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SMOKE PENETRATION STUDIES AT OVERBROOK TS OTTAWA, ONTARIO

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ABSTRACT

Overbrook TS is the latest design in Dual Element Spot Network (DESN) transmission station buildings for the prevention of total metalclad switchgear contamination by soot and smoke if a switchgear cell failure occurs. The part of the building that houses the transformer and metalclad switchgear cells is symmetrically divided in half. Each half has four rooms of two different sizes (~48 m^3 and ~330 m^3). Six smoke tests were performed at Overbrook TS to assess the penetration of smoke into adjacent rooms, to determine the effectiveness of smoke removal by the ventilation system and to note the response and behaviour of the smoke detection system. Smoke measurements were made for each of three ventilation schemes and each room size. The test results indicated that the physical barriers (ie, walls and doorways) were effective in containing the smoke for each size of room. The ventilation system was found to be effective in removing the smoke. The smoke detector(s) responded quickly to the smoke but were insensitive to residual smoke after the smoke detector reset.

1.0 INTRODUCTION

At the request of Transmission/Stations Programs Department, the Electrical and Chemical Research Departments of Research Division, are investigating a new building design and ventilation

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system designed to contain and remove the smoke and soot generated when a metalclad switchgear cell failure occurs. Almost all of the Dual Element Spot Network (DESN) transmission stations currently in service have the transformer breaker cell and feeder cells housed in a single large room. Recently, at Slater TS and King Edward TS in Ottawa, smoke and soot generated during a switchgear cell failure caused the station to trip out. This was traced to extensive soot deposition on other healthy units, causing them to also short out. Overbrook TS is the latest design in transmission station buildings with the capability of isolating and then ventilating smoke/soot if a transformer breaker cell or feeder cell failure occurs. The smoke venting facilities incorporated into the design at Overbrook TS should limit or eliminate stations outages of the type observed at Slater and King Edward TS.

The Environmental Science Section of Chemical Research received a request from Transmission/Stations Programs to undertake a full-scale smoke penetration study at Overbrook TS prior to the installation of the metalclad switchgear assemblies. It was intended that the full-scale smoke tests at Overbrook TS would complement smoke containment studies being done at Electrical Research.

A transmission station with one 13.8 kV DESN unit usually has four transformer breaker cells and seven to eight feeder cells associated with each transformer breaker cell. In the new building, each transformer breaker cell would be isolated in a small room and its associated bus tie and feeder breaker cells installed in an adjacent large room. The smoke studies at Overbrook TS involved the generation of smoke in one of the small transformer breaker rooms and in one of the large metalclad switchgear rooms and then determining the amount of smoke penetrating into the adjacent rooms. Three smoke tests involving different ventilation scenarios were performed for each size of room. These were:

(a) individual room ventilation systems were turned off for the entire test period,

(b) ventilation systems for each room were off until triggered on by the first smoke detector to annunciate, and

(c) ventilation system for the smoke generation room was on from the beginning of the smoke test.

Six tests were completed. Each test involved: (i) collection of smoke density and deposition data using filter packs and a real-time aerosol counter, (ii) video recordings of the smoke generation and smoke penetration into adjacent rooms and out of the building, and (iii) photographs of the sampling locations and test site.

The test method is briefly described in Section 2.0. The test results and a brief discussion are presented in Section 3.0. Conclusions are listed in Section 4.0 and Recommendations in Section 5.0.

2.0 EXPERIMENTAL SET UP FOR SMOKE PENETRATION TESTS

A schematic view of Overbrook TS with the smoke test experimental layout is shown in Figure 1.

The eight rooms that contain the transformer breaker and switch-gear cells, four small and four large, are arranged symmetrically in each half of the building. The smoke tests were undertaken in only one of the large and small rooms as the smoke behaviour was assumed to be representative of the other rooms. The volume of each large room was about 330 m^3 (12.1 m x 5.8 m x 4.7 m) and each small room about 48 m^3 (1.75 m x 5.8 m x 4.7 m). All the rooms in the complex had a motorized damper mounted onto a louvered opening in the outer wall for air intake and an exhaust fan mounted on the ceiling (no damper). There are a total of 24 doorways, 8 exterior and 16 interior, in the Overbrook TS building through which smoke and soot can migrate.

For each large room, an air intake consisting of a storm louver, bird screen and motorized damper with a square opening of 0.375 m^2 (net area) was set onto the outer wall near the centre of the building close to the floor. The air exhaust, a powered roof ventilator, for each large room was mounted on the ceiling diagonally opposite the air intake. The fan was rated at 85 m^3/min (1413 L/s, 3000 CFM) with the room air drawn through a square hole with 0.46 m^2 net area and discharged through a 0.12 m^2 duct to the outside air.

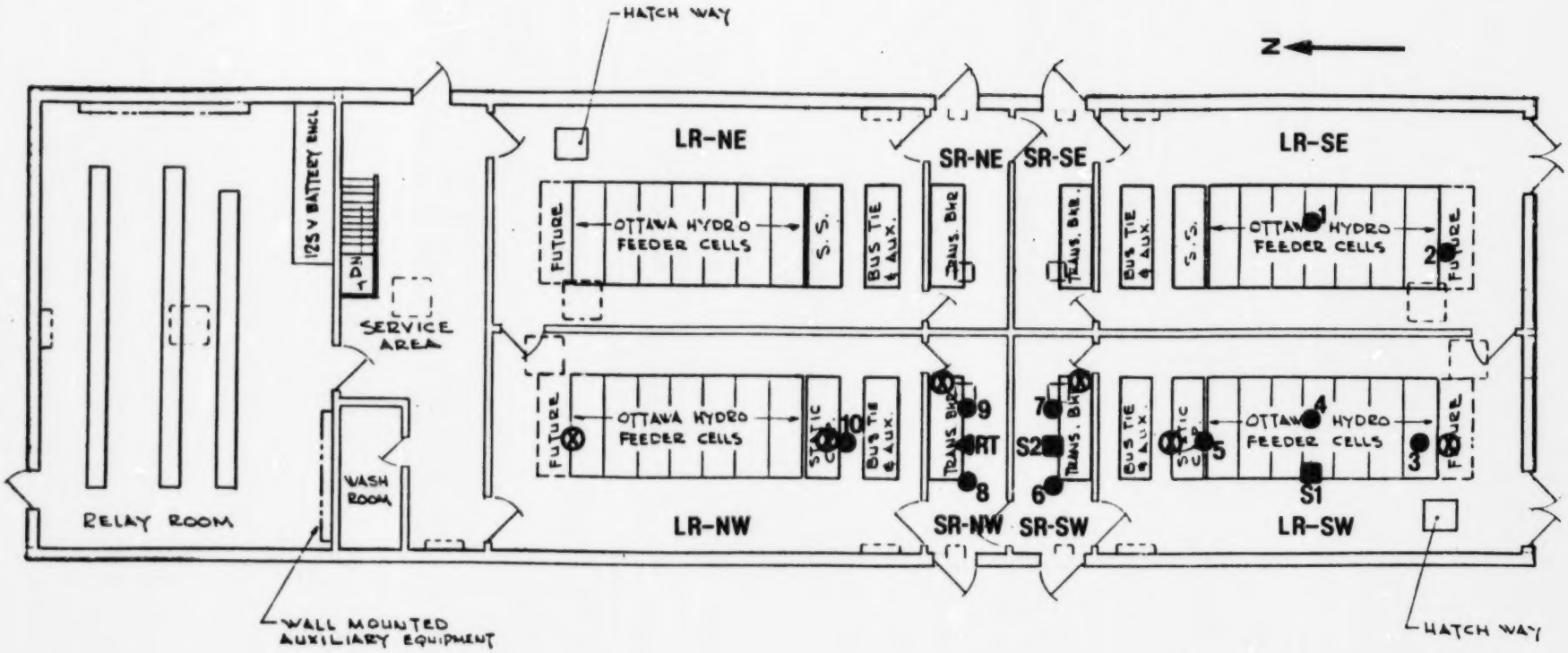
For each small room, the air intake consisting of storm louver, bird screen and motorized damper with the incoming air entering through a ~0.25 m^2 (net area) square opening, was mounted ~3 m above the floor level onto the building exterior wall above the large exit door. The air exhaust (powered roof ventilator) was mounted on the ceiling near the centre of the room. It had a rating of 17 m^3/min (284 L/s, 600 CFM) with the smoke drawn through a 0.305 m^2 (net area) opening and discharged out of the building through a 0.046 m^2 opening.

There was a ventilation system in the basement of the building but it was shut off during the testing.

The ventilation system for each room was installed strictly for the removal of smoke. The air intake and powered air exhaust in each room were activated only when the smoke detector in that specific room was triggered. The ventilation system could be used for heat removal as well, if a temperature switch were installed.

Figure 1

Overbrook TS - Experimental Layout
for Smoke Penetration Studies



Legend

- ● Air Sample Location
- ▲ RT - Real Time Aerosol Monitor
- ⊗ Smoke Detector
- ■ Smoke Generation
- Exhaust Fan - Large Room
- Exhaust Fan - Small Room
- Motorized Damper - Large Room
- Motorized Damper - Small Room

The east-west walls between each large and small room were incomplete to allow the installation of the transformer breakers and switchgear cells. To simulate the final structure, 3 mil thick polyethylene sheeting was positioned on each side of the openings and sealed with double-sided tape and duct tape.

Smoke detectors, DICON Model 330L using the ionization principle, were installed in the test rooms by Ottawa Hydro. One detector was ceiling-mounted in each small room and two in each large room. The smoke detector(s), motorized damper and the exhaust fan were electrically interconnected. The motorized damper and exhaust fan for a specific room would be activated only when the smoke detector for that room was triggered. After the smoke detector no longer sensed smoke, it underwent a reset and in doing so turned the exhaust fan off and closed the damper.

The white/grey depositless smoke used for the penetration studies was generated from smoke candles obtained from the Safety Supply Company of Canada. The density of the smoke generated was comparable to the smoke generated by arcing. To simulate equal amounts of smoke in given volume of space, a single 3-min duration smoke candle was used for each test in the small room, whereas for each test in the large room two 5-min duration smoke candles fired simultaneously were used to fill the room with smoke. The smoke candles were lit remotely. The smoke generation locations (S1 and S2) are shown in Figure 1.

A total of 10 air samples were collected for each experiment. The sampling locations are listed in Table I and shown on Figure 1. Each air sampling location had a 47-mm Millipore HAWP 04700 0.45 μm pore size filter that had been previously weighted. The filter was set into an open-face filter holder which was supported on a stand ~2 m above floor level. Polyethylene tubing (9.525 mm OD) was run from the filter pack to a calibrated sampling pump. After each smoke test the filters were removed and stored in plastic petri dishes until the final weights could be obtained.

To place the data generated during the smoke tests into a form where deposition assessments are possible, it was necessary to generate a parameter which correlated the measured smoke densities with some physical property of the polluted environment. The property chosen was called the minimum soot deposition density. The minimum soot deposition density (MSDD) is the amount of contaminant collected on an air sampling filter that is then equally distributed onto the spherical surface surrounding the known volume from which the soot was collected/1/. A minimum soot deposition density value was calculated from each air sample collected. This MSDD value would be comparable to the soot deposited by gravitational settling/impaction to the various surfaces, (ie, electrical insulators).

TABLE I

Smoke Sampling and Generation Locations Used During the Smoke Penetration Studies at Overbrook T.S., Ottawa

Sample Number	Room Location by Direction	Sample Position in Each Room	Sample Flowrate (L/min)
1	Southeast Large Room	Center of Room	10.4
2	Southeast Large Room	7'from West wall 7'from South wall near the doorway	10.4
3	Southwest Large Room	9' 10" from South wall on North-South Centerline	12.2
4	Southwest Large Room	7' 6" from East wall on East-West Centerline	13.2
5	Southwest Large Room	29' 6" from South wall on North-West Centerline	13.5
6	Southwest Small Room	12' 6" from East wall on East-West Centerline	13.0
7	Southwest Small Room	6' 4" from East wall on East-West Centrline	9.0
8	Northwest Small Room	12' 8" from East wall on East-West Centerline	9.0
9	Northwest Small Room	6' 4" from East wall on East-West centerline	9.0
10	Northwest Large Room	6' 7" from South wall on North-South Centerline	9.0
S1	Southwest Large Room	Smoke Generated for 5 min at 7' 6" from west wall along east-west center line of large room	
S2	Southwest Small Room	Smoke generated for 3 min at center of small room	
RT	Southeast & Southwest Small Rooms	Real time particulate monitor for detection of smoke penetration into adjacent rooms ~1.5 M above floor in center of room.	

Note: See Figure 1 for sample locations relative to the dampers, exhaust fans and smoke detectors.

The Bauch & Lomb Model 40-1a aerosol monitor was set up in a room adjacent to the room where smoke was generated. The monitor inlet was placed ~1.5 m above floor level and the output was recorded on a Philips single pen chart recorder. The internal calibration of the instrument was checked prior to each experiment.

A video tape camera was used to record each of the smoke tests. In addition, photographs of the sampling locations and building site were also taken. The video tapes and site photographs are on file with the Environmental Science Section of Chemical Research. They can be examined upon request (File: 836.512).

3.0 RESULTS AND DISCUSSION

3.1 Exhaust Fans Off and Intake Air Damper Closed

Smoke was generated in the small room (SR-SW) for 3 min at the beginning of the sampling period. The air samples were collected for 7.5 minutes before the room was cleared. Smoke was found to leak out of the exhaust vent on the roof, out of the damper in the exterior wall, along the large exterior door seam as well as under and around the interior doors into the adjacent large and small rooms. After about 2 min of smoke generation, a small amount of smoke was detected by the real-time monitor in the adjacent small room (SR-NW). Any smoke ingress into the adjacent rooms may have been aided by personnel entering the adjacent rooms for observation purposes. A trace amount of smoke was visually detected in the adjacent large room (LR-SW) but the filter sample nearest the smoke generation room did not sample a measurable amount of smoke. The smoke generated in the small room was evenly distributed.

For the large room (LR-SW), 5 min of smoke was generated from two 5-min duration smoke candles fired simultaneously at the beginning of the sampling period. Air samples were collected for 7.5 min. Smoke was found to escape through the ceiling air exhaust, along the seams of the large double service doors in the exterior south wall and out the floor level air intake. Smoke was not detected in the basement. A little smoke was detected by the real-time monitor which was sampling in the adjacent small room (SR-SW).

During the test day, the winds were from the north at about 10 to 20 km/h. The wind generated a small air flow in the building causing the smoke to migrate toward the south wall. The air samples taken in the smoke generation room were parallel to the wind direction. The MSDD results indicated an increasing gradient in smoke density towards the south wall. The smoke was not well mixed as a distinct vertical gradient could also be seen. The air samples collected in the other rooms showed no significant smoke penetration.

Wind direction appears to have a significant effect on smoke distribution within the building when the exhaust fans are not on and the dampers are closed. Smoke penetration between rooms was minimal (<4%) and between station halves undetectable either visually or by air sampling.

The MSDD results for conditions in which the fans were off and the smoke was generated in a small and a large room are listed in Table II and are shown in Figure 2.

3.2 Fans On and Damper Opened by Triggered Smoke Detector

The smoke detector in the small room was not placed in the natural airflow path between the damper and the exhaust fan due to the unavailability of a proper ceiling support. For the large room, the two smoke detectors were placed on ceiling supports in locations that were influenced by the airflow between the damper and the exhaust fan. The response time of a detector to smoke in the large room was shorter (~25 s) than in the small room (~35 to 40 s) because of enhanced airflow past the detector. The same effect was observed for the case in which the fans were on, discussed in the following section. The smoke detector locations are shown in Figure 1.

The smoke alarm in the small room triggered after about 35 s of smoke production. The smoke density measured with the fans operating was about 1/3 of that measured without the fans operating over the same sampling time period. The smoke was found to leak out the exhaust vent, the damper and the door seam prior to activation of the ventilation system. After the ventilation system was activated, the smoke came only out of the exhaust vent and a significant air inflow could be detected at the outside door seam. When the smoke detector reset and shut down the ventilation system, a visible amount of smoke remained in the room. The smoke detector was found to trigger intermittently as denser parcels of smoke reached the detector. The ventilation system had about a 15-s delay prior to reaching full efficiency. The on/off cycling of the smoke detector was <15 s. Any additional smoke removal by the smoke detector cycling of the ventilation system was minimal and in fact may lead to possible motor damage from the power surges that occur.

For the large room, a smoke detector triggered after ~25 s of smoke production. The ventilation system caused the smoke to be well mixed as the smoke density measurements indicated equivalent smoke density throughout the room during the sampling period. Before the ventilation system came on, the smoke leaked out of the ceiling exhaust vent and the seams of the large double doors in the south wall. Smoke was not detected coming through the hatchway into the basement. After the ventilation system was activated, smoke came out of the exhaust vent only. A significant air inflow could be detected at the door seams of the large

TABLE II

Minimum Smoke Deposition Density Results
for the Smoke Penetrations Tests
at Overbrook T.S., Ottawa

		Minimium Smoke Deposition Density (MSDD) (ug/cm2)					
Smoke Generated		Large Room (LR-SW)			Small Room (SR-SW)		
Sample Location	Sample No.	Fans Off	Fans Triggered	Fans On	Fans Off	Fans Triggered	Fans On
LR-SE-1	1	0.07	0.02	0.06	0.05	0.08	0.05
LR-SE-2	2	0.02	0.02	0.02	0.01	0.02	0.09
LR-SW-1	3	4.61	4.93	1.99	0.05	0.03	0.05
LR-SW-2	4	3.22	4.91	1.90	0.06	0.03	0.04
LR-SW-3	5	2.43	4.64	4.80	0.06	0.31	0.02
SR-SW-1	6	0.09	0.07	0.06	7.75	1.61	1.46
SR-SW-2	7	0.05	0.20	0.21	7.65	2.76	2.21
SR-NW-1	8	0.13	0.05	0.17	0.05	0.07	0.14
SR-NW-2	9	0.14	0.22	0.10	0.18	0.01	0.14
LR-NW-1	10	0.29	0.19	0.09	0.01	0.02	0.08
Smoke Detector Response		n/a	~25 s	~25 s	n/a	~35 s	~40 s

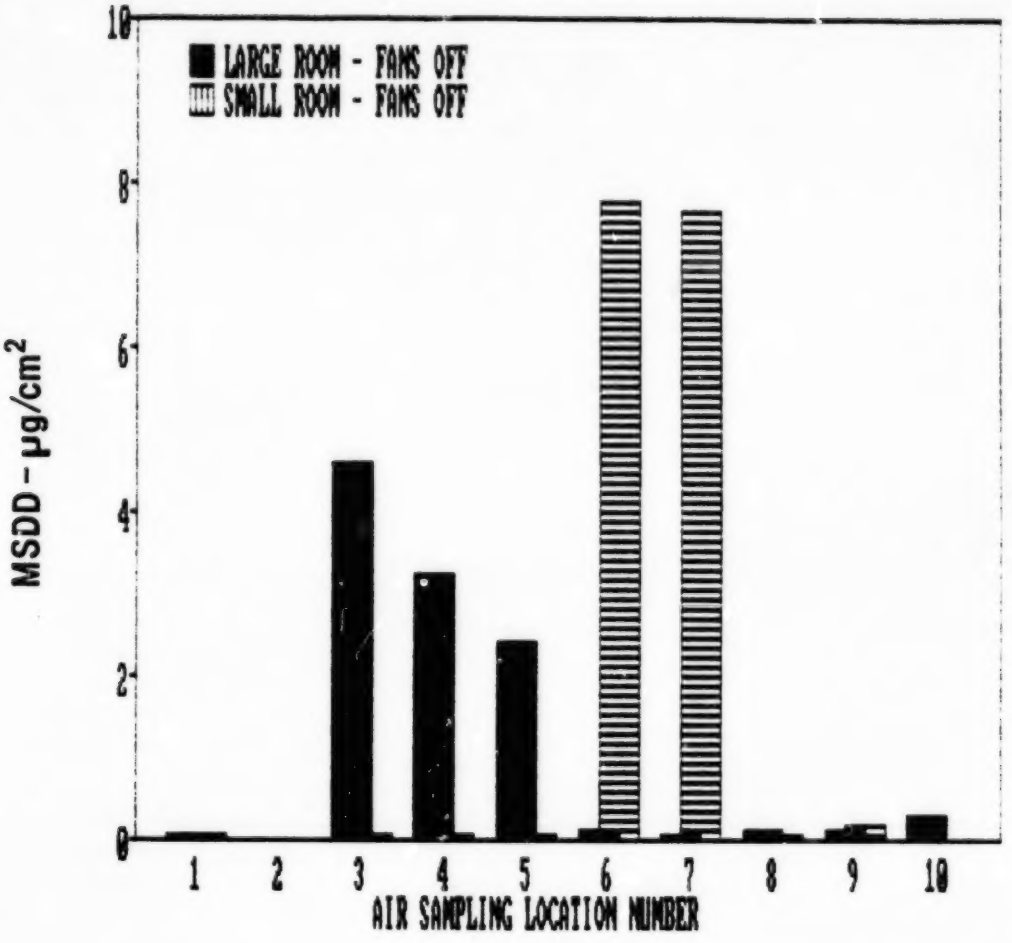


Figure 2

Smoke Penetration Studies - MSDD Results for
Small and Large Rooms with Fans Off

room. When the smoke detectors reset and shut down the ventilation system, a significant amount of smoke remained in the room. The smoke alarm was found to trigger intermittently as was found for the small room case.

The MSDD results for the small and large room cases are listed in Table II and shown in Figure 3. Smoke penetration into adjacent rooms was not observed.

3.3 Exhaust Fan On and Damper Open

The exhaust fan was turned on and the fresh air damper was opened in the small room from the beginning of smoke generation. The smoke alarm triggered after ~40 s. Smoke came out of the exhaust fan duct only. With the fan continually on, the small room was cleared of smoke in ~15 min after smoke generation was initiated. A trace of smoke was still detected in the air space along the floor level opposite the large outside exit door after the 15 min. Smoke was not detected in the adjacent rooms.

For the large room, the smoke alarm triggered after about 25 s of smoke generation. Smoke came out of the exhaust fan only. With the ventilation system on continuously, the large room was visibly clear of smoke in about 20 min. Trace amounts of smoke were detectable at ceiling level opposite the damper.

The MSDD results are shown in Figure 4 and listed in Table II. For both cases, smoke could not be detected in the adjacent rooms or in the basement.

Figures 5 and 6 summarize the effect of the three ventilation schemes on the MSDD values collected for the small and large rooms, respectively. The addition of ventilation to the small room reduced the MSDD values by at least 2/3. For the large room, the effect of ventilation was not as pronounced as for the small room. For the two ventilation schemes, fans triggered and fans on, an average reduction of 40% in MSDD values was found in the large room.

4.0 CONCLUSIONS

The following conclusions result directly from the smoke test program:

- The walls and doorways were effective barriers to smoke migration between adjacent rooms as long as the interconnecting doorways were closed.

- Trace amounts of smoke penetrated from the smoke generation room into the adjacent rooms along the door seams and at the thresholds of the doorways but this occurred only when the ventilation system was off in the smoke generation room.

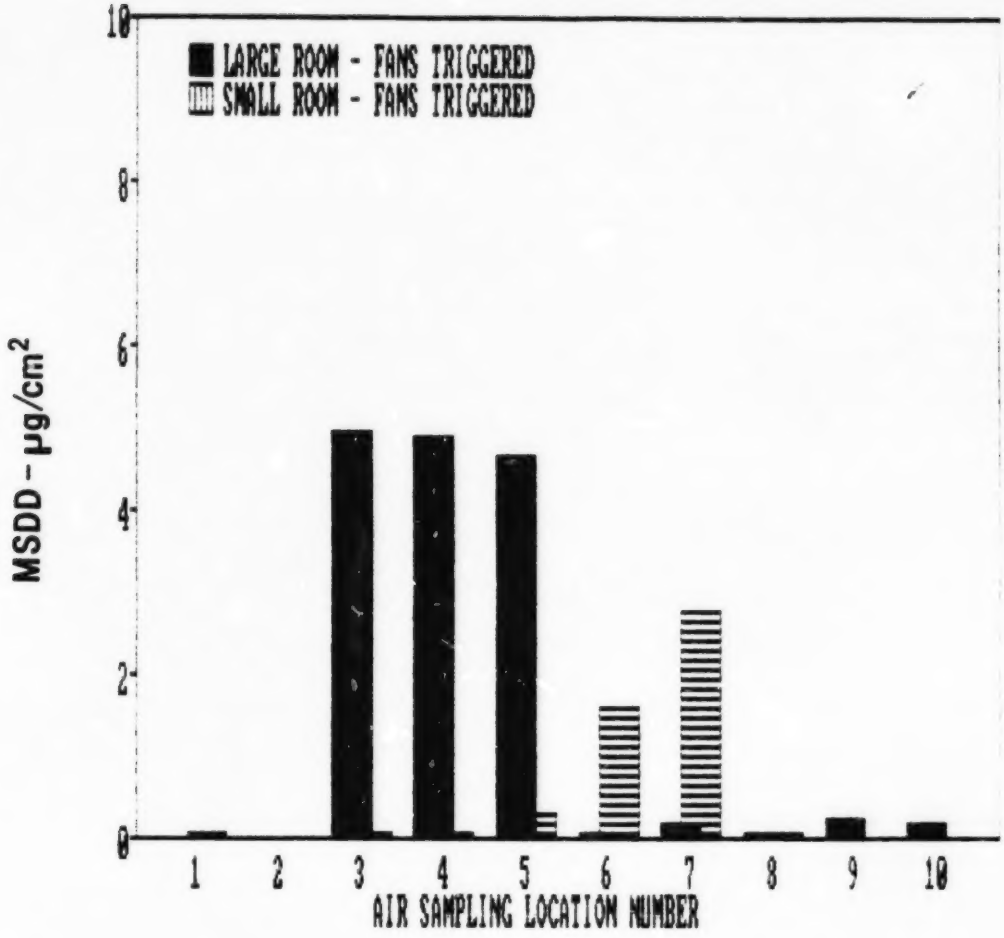


Figure 3

Smoke Penetration Studies - MSDD Results for Small and Large Rooms with Fans Triggered On by Smoke Alarm

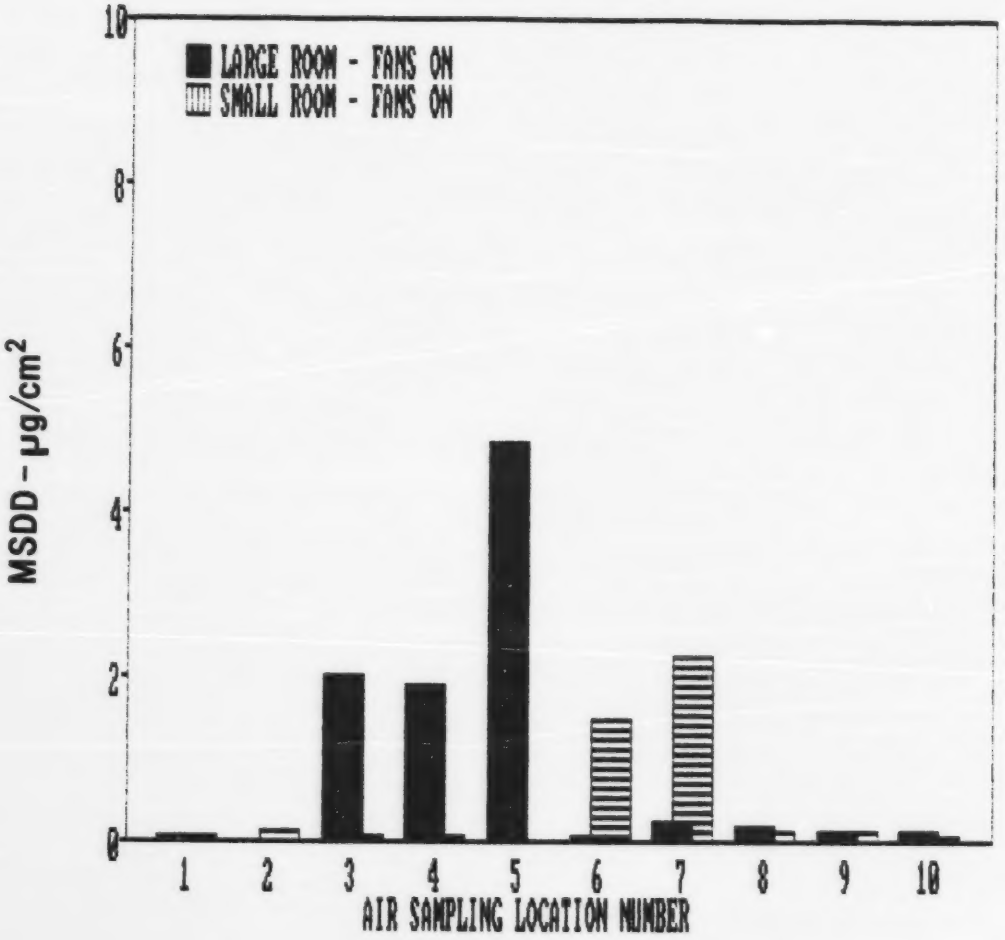


Figure 4

Smoke Penetration Studies - MSDD Results
for Small and Large Rooms with Fans On

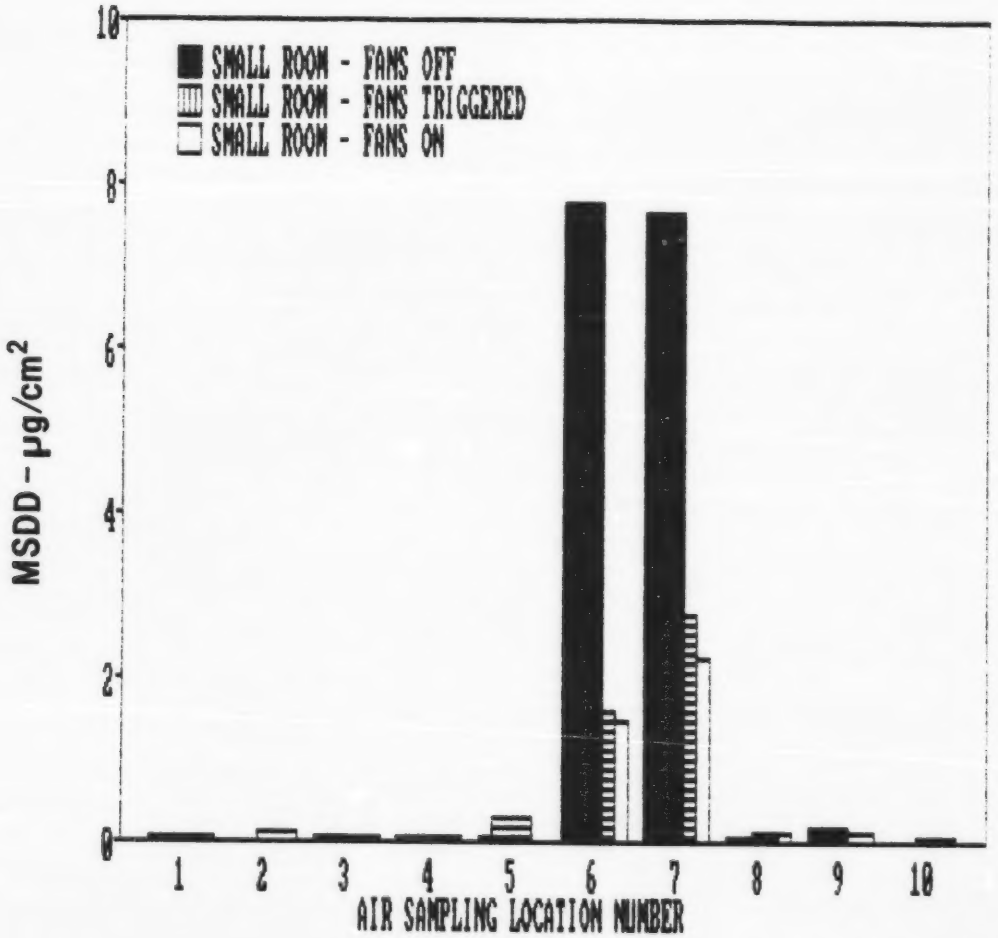


Figure 5

Smoke Penetration Studies - MSDD Results for Small Room

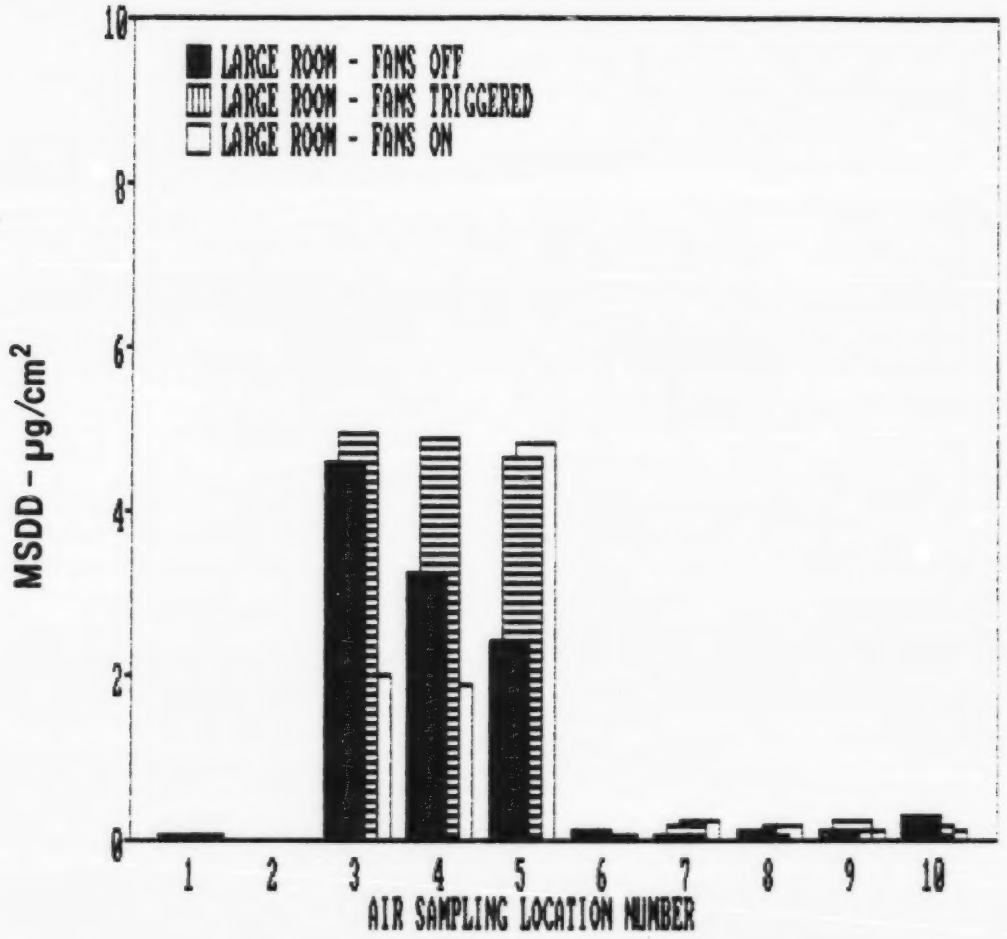


Figure 6

Smoke Penetration Studies - MSDD Results for Large Room

- With the ventilation system operating, no smoke was detected in the adjacent rooms.

- The smoke detectors responded quickly to the smoke but reset before all the smoke was removed from the room.

- The ventilation system was effective in clearing the smoke in the small and large rooms, if enough time was allowed for the system to operate.

- The fresh air dampers did not open completely. The incoming air was directed towards the ceiling rather than horizontally or slightly downwards into the room. This is especially important for the small room as the damper is mounted too high on the exterior wall.

- Outside wind direction has a significant effect on the smoke dispersion in the large room, when the ventilation system is off.

5.0 RECOMMENDATIONS

It is recommended that the ventilation system, once triggered by a smoke detector, remain active until manually reset by the station operator.

It is also recommended that additional door seals be added to the doorways connecting the large and small rooms and sweeps be added to the bottom of doors that do not have thresholds to minimize smoke migration in the event the individual room ventilation systems do not function during an arcing fault.

It is recommended that the motorized damper in each large room be adjusted in a manner that allows the incoming air to be directed horizontally or slightly down into the room. Similarly, it is recommended that the motorized damper in the small room be adjusted so that the incoming air is directed down into the room. The best solution would be to relocate the air intake about 1 m above the ground. This would require developing a way to install it in the large exterior doorway.

It is recommended that the smoke detectors selected for the station be mounted in ceiling locations that utilize the natural air movement in the room to enhance the detection of smoke.

It is recommended that the smoke removal system be set up for the removal of excessive heat by the addition of temperature sensitive switches.

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REFERENCE

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